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Technical Report No. 11

THE AUTOMASTS: AN AUTOMATICALLY-RECORDING TEST OF ELECTRONICS TROUBLE SHOOTING

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Principal Investigator

Glenn L. Bryan

Project Director

Nicholas A. Bond, Jr.

Research Assistants

Harold R. LaPorte, Jr.
Stanley A. Summers

Prepared for

Personnel Analysis Division
Bureau of Naval Personnel

Personnel and Training Branch
Psychological Sciences Division
Office of Naval Research

DEPARTMENT OF PSYCHOLOGY

UNIVERSITY OF SOUTHERN CALIFORNIA

PREFACE

This report is the eleventh in a series produced by the Electronics Personnel Research group. Technical Reports No. 9 through 12 are especially oriented to the domain of electronics trouble shooting, and their titles are listed below:

9. A Methodological Study of Electronics Trouble Shooting Skill: I. Rationale for and Description of the Multiple-Alternative Symbolic Trouble Shooting Test.

   A description of a new type of test format designed for measuring some aspects of trouble shooting skill, and a discussion of the conception of trouble shooting on which it is based.

10. A Methodological Study of Electronics Trouble Shooting Skill: II. Intercomparisons of the MASTS Tests, a Job-Sample Test, and Ten Reference Tests Administered to Fleet ETs.

    A report of the results of the administration of two forms of the MASTS Tests, its progenitor job-sample test, and a battery of achievement and ability oriented reference tests to a sample of ETs from ships undergoing repairs in the Long Beach Naval Shipyard.

11. The AUTOMASTS: An Automatically-Recording Test of Electronics Trouble Shooting.

    A detailed description of an automatically-recording version of the MASTS Test. Mechanical and administrative features of the test are presented. The test problems and proposed scoring procedures are discussed, and a variety of applications are suggested.

12. An Experimental Battery for Measurement of the Proficiency of Electronics Technicians.

    A report of the results of administering the AUTOMASTS Test and a battery of nine printed electronics tests to a large sample of electronics maintenance personnel from the Pacific Fleet.

ACKNOWLEDGMENTS

The research reported in this series reflects the contribution of a large number of persons within the Military Establishment. Grateful appreciation for this assistance is extended to the Personnel Analysis Division, Bureau of Naval Personnel; the Personnel and Training Branch of the Psychological Services Division of the Office of Naval Research, and the Electronics Coordinator's Section of the Office of Chief of Naval Operations.

Appreciation is expressed to the Commandant, Twelfth Naval District, for providing testing space. The availability of subjects for experimental testing was made possible through the cooperation of several Naval commands. Special acknowledgment for making these arrangements is due to the following staff officers: LCDR R. S. Umbarger, Air Force Pacific Fleet; LT A. E. Rose, Cruiser Destroyer Force, Pacific Fleet; LT J. Alotis, Amphibious Force, Pacific Fleet; LT E. B. Rogers and LT E. B. Mehinskie, Service Force, Pacific Fleet.

Two engineers, Mr. Richard Beaver and Mr. Elmer Morris, rendered valuable technical assistance in translating the AUTOMASTS concept into a practical machine. The contribution of Mr. Morris was especially appreciated, as he was responsible for several design features and supervised the fabrication and assembly of the mechanical parts.

Mr. John Hills, Research Assistant, contributed materially to equipment procurement and assembly. Thanks are also due to Mr. Don Roth of Western Television Institute and Messrs. Don Ketchum and Clifford Byard of American Television Laboratories of California who carefully reviewed the AUTOMASTS test problem material.

ABSTRACT

This report is one of a series concerned with the analysis and measurement of electronics trouble shooting behavior. An automatically recording testing device called the AUTOMASTS is described in detail. Problems used in the device and procedures for administering the test are presented. Proposals for scoring the response records are introduced along with suggestions for research applications of the instrument.

TABLE OF CONTENTS

TABLE OF CONTENTS
(cont'd)

LIST OF TABLES

LIST OF FIGURES

THE AUTOMASTS: AN AUTOMATICALLY-RECORDING TEST OF ELECTRONICS TROUBLE SHOOTING

I. INTRODUCTION

The development of modern electronic systems has necessitated the development of procedures for evaluating and analyzing the performance of men engaged in repair of electronic equipment. This report describes an experimental, automatically-recording, proficiency test used to assess the capabilities of naval electronics repairmen. Since the testing device is new, it is described in detail. The electronics "troubles," or problems, used as subject matter during the initial tryout of the testing machine are described, and the procedure for administering the test is given. Mention also is made of the possibilities for scoring the performance records. The results of the administration of this test along with a battery of more conventional tests will be presented in Technical Report No. 12.

Historical Background

The AUTOMASTS Test has evolved through several stages. Its immediate predessor is the MASTS Test. That test and its development are described in Technical Report No. 9.[1] The AUTOMASTS

[1] A Methodological Study of Electronics Trouble Shooting Skill: I. Rationale for and Description of the Multiple-Alternative Symbolic Trouble Shooting Test.

Test is essentially a refined and automatically-recording form of the MASTS Test and is, therefore, based upon the same conception of trouble shooting and test rationale.

In the summer of 1953 the MASTS Test was individually administered to a sample of 36 electronics technicians from the Pacific Fleet at the Long Beach Naval Shipyard. Each man took the test along with trouble shooting problems in actual electronic equipment. The results of that study are reported elsewhere.[2] For the purpose of the present report it is sufficient to say that the results indicated that trouble shooting scores on the MASTS Test were rather good predictors[3] of trouble shooting scores on actual electronic equipment. At the conclusion of the field study it was decided to construct an automatically-recording form of the test and to adapt to the automatic model some of the same problems that had been tried out during the Long Beach testing.

The Advantages of an Automatically-Recording Test

There are a number of advantages to an automatically-recording test as compared with the same test administered on the prototype equipment, i.e., the actual electronic gear. Most of these are obvious, but a few are worthy of mention. One of the main advantages is

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[2] See our Technical Report No. 10 entitled, "A Methodological Study of Electronics Trouble Shooting Skill: II. Intercomparisons of the MASTS Test, a Job-Sample Test, and Ten Reference Tests Administered to Fleet ETs."

[3] Rank order correlations between the job sample total score and the MASTS total score range from 0.60 (where the score is the number of problems solved) to 0.77 (where the score is the median time of solution).

that the test may be simultaneously administered to as many experimental subjects as the number of testing machines available. The implications of this may not be striking to one who has not attempted to obtain complete response records of the performance of a man while he is repairing a piece of equipment, but those who have done so can confirm the arduous nature of the task.

Under such circumstances each observer has to be carefully trained in the techniques of observing and recording as well as in the technical subject matter of the job. Only one experimental subject's performance may be observed and recorded at a time. In order to test more than one man at a time on the actual equipment, each experimental subject has to be provided with a set of electronic gear, reference materials, and test equipment. Each subject requires the services of a trained observer. Because of these and other practical requirements, the number of cases studied in this manner is usually so small that adequate statistical treatment of the response records is difficult.

When automatically-recording testing machines are employed, one observer can supervise several machines at one time and the collection of data for a large number of cases becomes economically feasible. It is unnecessary for the administrator to participate in the testing in any way except to change the problem in the machines and generally supervise the men taking the test. As a result, relatively untrained and electronically naive test administrators can be used.

Another advantage is that with an adequate automatic recording

mechanism there are few recording errors or misses such as may occur when an observer has the responsibility for recording every step that the subject makes in the course of his trouble shooting.

A further advantage is that the response records are presented in a standardized manner - the machines do not adopt idiosyncrasies of style which consequently make subsequent analysis of the data difficult. Finally, there is an advantage of shorter administration time. The use of the machines enable the men to work at a faster rate than that possible on the operating equipments, so each man can attempt more problems during a standard testing session.

II. DESCRIPTION OF THE AUTOMASTS MACHINE

The Outside of the Machine

An exterior view of the AUTOMASTS testing machine is shown in Figure I. The machine is contained in a plywood box (approximately 21" x 25" x 6") with a metal lid. The entire assembly is mounted so that the plane of the lid makes an angle of 20 degrees with the table top. This arrangement enables the man working with the equipment to read the problem information as it is exposed, without assuming an uncomfortable position. A crank handle (I - K)[4] extends from the right side of the machine. A cast iron handwheel (I - F) is attached to a vertical shaft which protrudes through the center of the lid. The tapered information slot (I - L) at the right of the handwheel is

[4]Throughout this section of the report parenthesized notations refer to the figure details. For example, (I - K) indicates that the crank handle is labeled "K" in Figure I.

labeled by means of a plastic strip of "action" labels (I - J) cemented to the lid above the slot. The slide-pointer (I - M) or "action selector" may be set in any one of the five labeled positions. Red and green effect indicator lights (I - C) are located at the upper left-hand corner of the lid. These lights are also identified by plastic labels (I - D) cemented to the lid. The lid is continously hinged to the box. Slide fasteners (I - G) located at the right and left edges of the lid fasten the lid firmly when it is in the closed position. A stiffening brace (I - B) supports the lid near its center. The rubber-padded bracket (I - A) on the outside back of the box serves as a rest for the lid when the box is open. A plastic knob (I - I) and pointer are affixed to a rotating shaft which protrudes from the left side of the machine and a scale (I - H), calibrated to time in minutes, is fastened to the side of the box beneath the pointer tip.

An arrangement of shutters (III - D) is interposed between the lid of the machine and the problem information so that the experimental subject can obtain problem information by following specified procedures. When these procedures are followed, a portion of the shutter opens (III - F) and problem information can be read through the aperture. The portion of the information slot to the right of the shutter (III - G & H) is always open and allows the subject to see the position of the problem information disk.

<u>The Way the Machine is Used</u>

General procedures for the administration of the AUTOMASTS test will be presented in Section IV of this report, but a brief

Key for Figure I

A. Lid support

B. Stiffening brace

C. Effect indicator lights

D. Effect indicator light labels

E. Electrical cord

F. Center handwheel

G. Lid fasteners

H. Timer scale

I. Timer reset knob

J. Action labels

K. Crank handle

L. Information slot

M. Slide-pointer

N. Slide-pointer knob

O. Traverse slot for slide-pointer stud

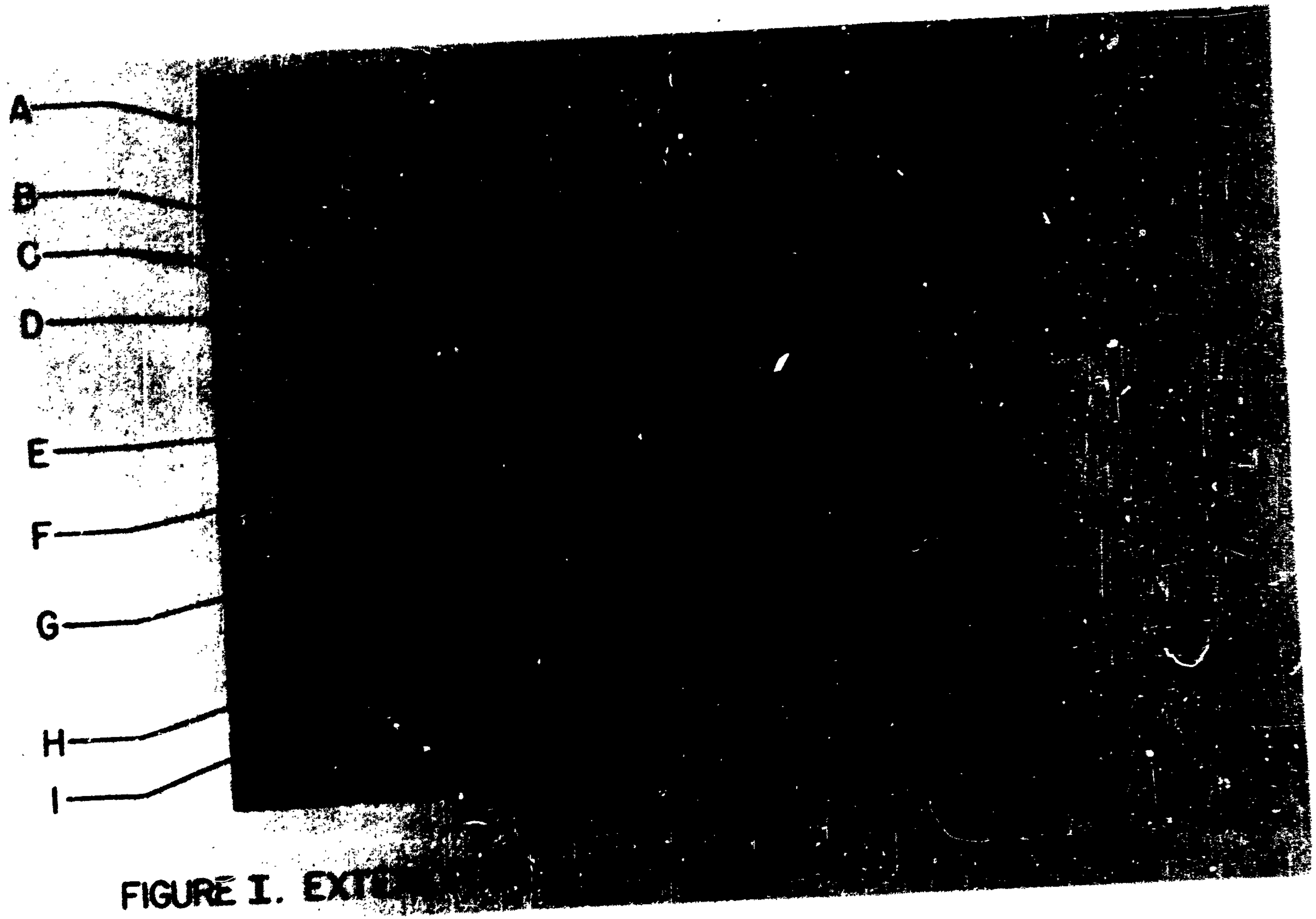

FIGURE I. EXT

description of the task of the experimental subject is given here in order to facilitate the further description of the machine.

Each experimental subject is provided with an AUTOMASTS testing machine, a set of schematic diagrams,[5] and other reference material. At the beginning of a problem he is handed a symptom card bearing the output characteristics of the electronic equipment upon which the problem is based. For example, if the problems are based upon a radio receiver, the legend on the symptom card might read "no sound at any station." This means that the set cannot receive on any frequency. The task of the experimental subject is to find and correct the difficulty. He does this by sampling a large number of test equipment readings obtained at various points in the circuit or by determining the effects of substituting parts.[6]

In its present form the machine permits him to determine the results of applying four types of test equipment to the radio receiver circuit. These are: a signal generator,[7] an AC voltmeter, a DC voltmeter, and an ohmmeter. Four of the five plastic labels above the tapered slot on the lid correspond to these test equip-

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[5]Copies of these schematic diagrams appear in the Appendix.

[6]In many ways the testing situation resembles the situation which would exist if the person attempting to solve the problem were on one side of a black curtain with the malfunctioning gear, a set of test equipment, and a trained technician on the other. In effect, the man attempting to solve the problem asks the unseen technician to make certain checks at particular points in the circuit and to report the results.

[7]For pulse-forming circuits an oscilloscope is substituted for the signal generator.

Key for Figure II

A. Hole for center shaft
B. Hinge
C. Information slot
D. Effect indicator light sockets
E. Delay system micro-switch
F. Delay system relay
G. Delay timer

H. Center shaft
I. Shutter support plate
J. Problem-information disk
K. Problem-information disk indexing
   hole and pin
L. Printing disk
M. Indexing disk

N. Positioning bearing
O. Locking timer
P. Supply spool
Q. Take-up spool
R. Paper tape (showing printed record
   of trouble shooting steps)
S. Printer holding bracket

T. Printing unit
U. Paper advance knob
V. Mechanical linkage
W. Shutter support post
X. Shutter advance bar
Y. Shutter
Z. Slide-pointer stud

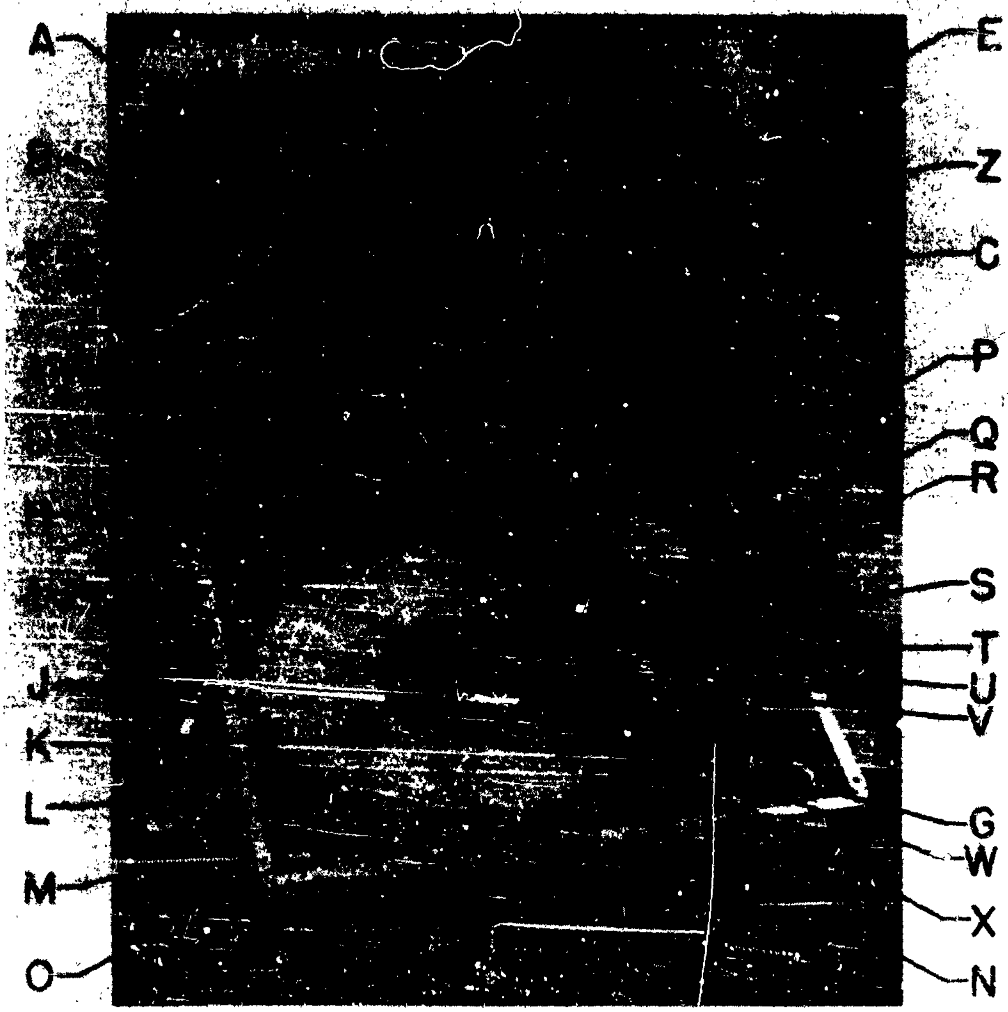

FIGURE II. INTERIOR VIEW OF
AUTOMASTS TESTING MACHINE

ments. The fifth label reads, "Replace or Adjust Component." When the slide-pointer under the slot in the lid is positioned to one of the action labels (such as D.C. Volts) and the crank handle is pulled, the shutter opens in the information slot and reveals the information which would have been obtained if a DC Voltmeter had been applied to the actual electronic gear under the circumstances of the problem. When the slide-pointer is directed toward the "Replace or Adjust Component" position (and the crank handle is pulled) the subject receives the results of substituting a good tube, resistor, capacitor, or lead for one already in the circuit. The "Replace or Adjust Component" position may also be used to determine the effects of adjusting components, such as a tuneable condenser, which are suspected to be the cause of the trouble.

The results of the action of replacing or adjusting components are given by a pair of effect indicator lights in the upper left-hand corner of the lid. If the component replaced is the cause of the faulty output of the equipment, a green light labeled "gear normal" will come on. If the component replaced is not the cause of the symptoms, a red light labeled "no effect" will indicate that the set is still not functioning properly.

The experimental subject may make any of the four types of reading at any of 120 points in the circuit. Similarly, he may replace any one of 120 components. All the possible test points and all the replaceable components are numbered on the schematic diagram. To make a check at some particular point in the circuit, the subject rotates the center handwheel of the machine, in either

Key for Figure III

A. Stiffening brace

B. Action labels

C. Center handwheel

D. Shutter

E. Traverse slot for slide-pointer stud

F. Scope reading test point 92 viewed through open window in shutter

G. Component number

H. Test point number

I. Slide-pointer

J. Slide-pointer knob

Key for Figure IV

A sector of a problem-information disk for the radar circuit is shown in this figure; the complete disk is about 18 inches in diameter. The information is arranged in a series of concentric rings. Starting from the outside ring and working toward the center, the information rings are arranged in the following order:

Test point numbers (89 through 95 shown)
Component numbers (289 through 295 shown)
Waveforms, obtained on a test oscilloscope
DC volt readings
AC volt readings
Ohms readings

The innermost ring shown corresponds to the "Replace or Adjust Component" position of the slide pointer. No entries appear in this ring since the results of making replacements and adjustments are presented to the experimental subject by the effect indicator light system. It will be noted that the sector shown in Figure IV includes the reading which is shown in Figure III.

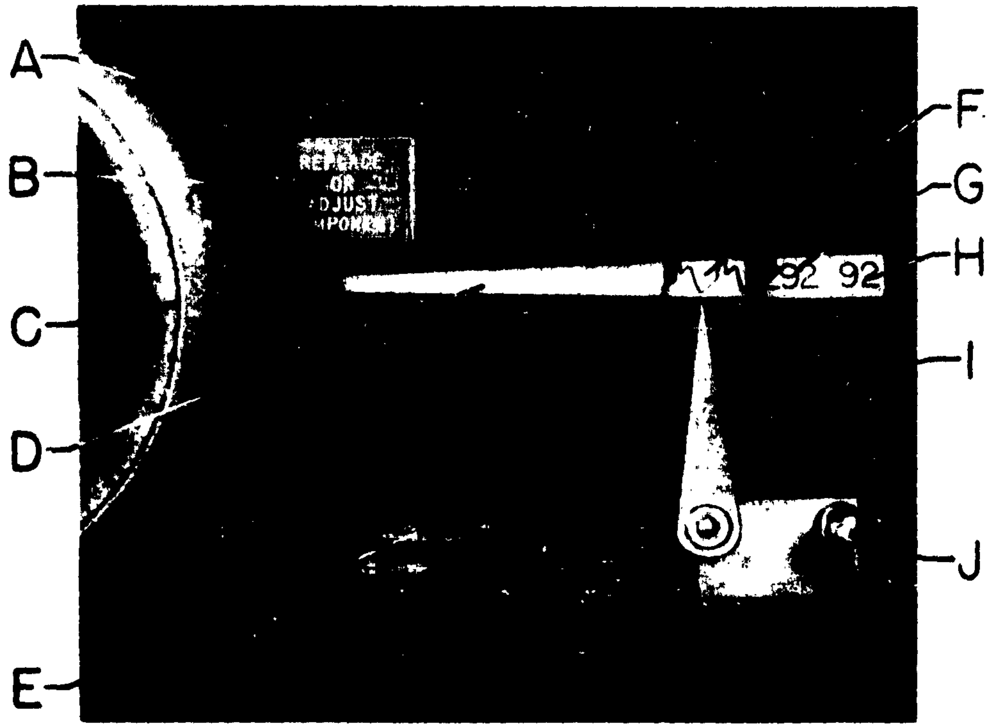

FIGURE III. FRONT PANEL DETAIL.

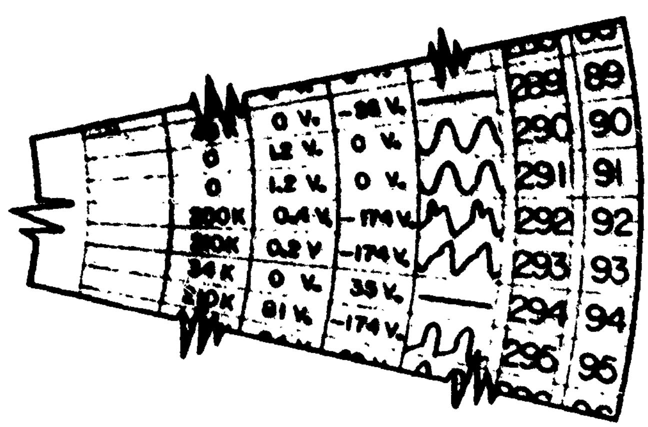

FIGURE IV. PROBLEM INFORMATION DISK DETAIL.

direction, until the number which corresponds to the point on the schematic comes into view in the space to the right of the shutter. He sets the slide-pointer to indicate the type of check that he wishes to make, and then he pulls the crank handle.[8]

<u>The Center Assembly</u>

The center handwheel of the machine is locked to the center shaft; the center shaft rotates in a ball bearing plate which is attached to the bottom of the box. When the subject turns the handwheel, the entire shaft rotates. Three large disks, each approximately 18" in diameter, are mounted on the shaft and turn with it. The indexing disk (II - M) is made of 1/8" steel and is mounted closest to the bottom of the box. One hundred and twenty wedge-shaped notches are milled into its circumference on 3 degree centers. When the crank handle is pulled a wedge-shaped dog fits into a notch so that the center shaft is locked at one position. When the crank handle is returned to its normal position, the dog is retracted and the center shaft may be rotated again. By means of spring tension, a small positioning bearing (II - N) is held in contact with the edge of the indexing disk. This bearing assists in the gross positioning of the indexing disk and also masks slight mechanical noises that might serve as cues to the solution of the problem if masking were not employed.

The printing disk (II - L) is mounted on the center shaft par-

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[8]Figure III shows the wave form on the test oscilloscope when it is connected between test point number 92 and ground.

allel to and about one inch above the indexing disk. The printing disk is made from 3/8" aluminum plate. Rectangular slots are milled in the edge of the disk on 3 degree centers to match the indexing notches in the steel indexing disk. Lead type slugs are cemented into the slots in the printing disk and protrude slightly beyond the circumference; the type slugs are arranged in consecutive order with numbers running from 1 through 120.

A thin aluminum problem-information disk (II - J) is situated 1½ inches above the printing disk. Information for each problem is arranged in concentric rings on a paper cemented to the aluminum disk (see Figure IV). New problems, i.e., troubles, are introduced into the machine by substituting new problem-information disks. A small indexing hole (II - K) in the problem-information disk fits over an indexing pin on the printing disk so the problem information is positively aligned with both the printing disk and the indexing disk. When the experimental subject turns the handwheel, the entire center assembly (center shaft, indexing disk, printing disk, and problem-information disk) is rotated. The rotation of this assembly brings the proper test point number under the open portion of the information slot in the lid of the machine. This action also positions the printing disk so that the number printed on the paper tape (II - R) corresponds to the number of the test point in the slot.

A heavy metal plate (II - I) fits over the center shaft and rests on the problem-information disk; this plate serves as a bearing surface for the free edge of the shutter.

The cast metal handwheel is fitted to the center shaft with a

retaining pin. Both handwheel and pin are removable so that the box lid may be opened to change the problem-information disks and to service the machine.

The Shutter Assembly

The position of the front panel slide-pointer is recorded on the paper tape by alphabetical symbols. Thus, "A" indicates a signal generator or oscilloscope reading, "B" indicates DC volts, etc. These symbols are printed by type slugs mounted on the shutter-advance bar (II - X). This bar slides on grooved studs which are fastened to the bottom of the box. When the crank handle is pulled, the shutter-advance bar is slipped along its mounting grooves by a system of mechanical linkages (II - V). The extent of this movement is controlled by the indexing slots in the shutter.[9]

Holes in the shutter slip over pins on the top of the shutter-support posts (II - W) to rigidly position the shutter with respect to the slide-pointer stud; spring clips hold the shutter on the pins. The shutter displays information on the problem-information disk by means of five staggered apertures which are located so that exactly one item of information can be viewed through the slot in the lid of the box at a time. Thus, if the subject turns the wheel to test point 76 and sets the slide

[9]These slots are shown but not labeled in Figure II. They consist of five vertical slots connected at their top by a horizontal slot. The vertical slots differ in length so as to properly position the shutter apertures and the shutter advance bar.

pointer to DC volts, only the DC volts reading will appear in the window when the handle is pulled. Of course, the subject can take any other type of reading at the same test point, by resetting the slide-pointer and pulling the crank handle, but each reading appears separately and is printed separately.

The shutter-indexing slots are situated toward the lower end of the shutter. When the lid of the box is closed and the crank handle is in the normal position, the slide-pointer stud (II - Z) engages the horizontal slot. When the crank handle is pulled, the slide-pointer stud restricts the movement of the shutter in the following ways: First, if the slide-pointer _is not_ pointing directly at some _one_ labeled location in the information slot, the shutter will _not_ advance and no information will be disclosed. Second, if the slide-pointer is pointing directly at some _one_ labeled location in the slot, the shutter is free to move relative to the slide-pointer stud until the shutter comes into contact with it. When the shutter is stopped by the stud, the appropriate aperture is properly positioned in the information slot so the subject may read the desired problem information from the disk, and the type of action taken is printed on the paper tape by means of the type slugs on the shutter advance bar.

The Printing Unit

The printing unit consists of a rubber platen, a typewriter ribbon drive system, and a paper advancing device. The unit is suspended between a socket in the bottom of the box and the printer-holding bracket (II - S). When the crank handle is pulled, the printer is

pivoted, by cam and roller action, around the axis of its supporting post. This movement forces the platen firmly against both the type that extends from the circumference of the printing disk and the type that is mounted on the shutter advance bar. When the crank handle is returned to normal position, the printer swings clear of the type and the paper tape is advanced by a ratchet. During this return stroke, the movement of the paper drives a friction wheel which advances the typewriter ribbon through a system of bevel gears. When necessary, the ribbon drive gears are reversed by pressing the end of the ribbon-reversal shaft. Thus, for each pull of the crank, a double entry is printed on the tape such as "A 40," "D 76," or "E 36;" the paper advances one-half inch, and the typewriter ribbon advances one-quarter of an inch.[10]

Effect Indicating System

A small plastic-covered bolt projects from the underside of each problem-information disk. This bolt makes contact with the blade of a mercury switch which is mounted on the inside-back of the box. When the problem-information disk is positioned so the number of the faulty component may be seen through the information slot in the lid of the box, the blade of the mercury switch is depressed. If the switch blade is depressed and if the slide-

[10] The printed letters refer to the type of reading and the printed numbers refer to the test point numbers. The printed entry "A 40" means that a signal was injected at test point 40; "D 76" means that resistance to ground was read at test point 76; "E 36" indicates that the cathode follower tube in the radar circuit was replaced.

pointer is in the "Replace or Adjust Component" position, the green "Gear Normal" effect indicator light comes on 30 seconds after the crank handle is pulled. If the blade of the mercury switch is not depressed, but the slide-pointer is in the appropriate position, the red "No Effect" indicator light will come on at the end of the delay interval.

This 30-second interval is controlled by a timer through a system of switches and a relay. The delay was introduced to minimize the likelihood of chance success and to serve as a deterrent to excessive parts replacement. The timer used could be varied from 0 to 60 seconds. Tryouts revealed that a 30-second delay was sufficient to discourage aimless replacing activity on the part of the subject, and still did not use up an inordinate amount of the time allowed for the diagnosis of each problem.

Cut Off Timer

Another timer is located in the lower left-hand corner of the box. This timer serves two functions. It indicates the elapsed time for each problem by means of a pointer and scale. It also activates an electrical switch at the end of a specified interval. This switch operates a locking relay which engages a projection on the cam so that the crank handle can no longer be pulled. In this manner, the machine may be set to automatically lock at the problem time limit or at the end of any prescribed period of time from 0 to 60 minutes.

Consideration was given to several methods for marking the paper tape with a time base. Provision was made to add a simple time indicating device to the printing mechanism but the actual mechanism will

not be added until the advantages of having the time base have been shown to warrant the additional expense.

Summary of the Description of the Machine

To summarize the description of the AUTOMASTS testing machine: It is essentially a box with a crank handle on the right side and a handwheel in the center of the lid. The experimental subject may turn the handwheel to bring any one of 120 test point numbers into view through a slot. A slide-pointer below the slot may be set to one of several positions; each position indicates a certain type of check that is made in the circuit. When the crank handle is pulled a small window opens and reveals the information that would be obtained by use of the indicated test equipment under the circumstances of the problem. The slide-pointer and handwheel can also be manipulated to determine the effects of replacing or tuning certain parts in the circuits. Every check or replacement that the experimental subject makes is automatically recorded in coded form on a paper tape. Accessory devices introduce delays into the replacement cycle, indicate elapsed time, and lock the crank handle at the end of a prescribed period.

III. AUTOMASTS TROUBLE SHOOTING PROBLEMS

The Basic Electronic Equipment

The problems employed in the present form of the AUTOMASTS were selected from those pretested in the MASTS format. They were originally developed by introducing malfunctions into functioning

electronic equipments. Those equipments were a superheterodyne radio receiver and a radar sweep generator assembled from a training kit[1] manufactured by the Philco Corporation. Several different circuits can be assembled from the available chassis. The selection of circuits for this test development was governed by the desire to employ circuits simple enough to permit relatively rapid subject orientation and yet complex enough to require realistic trouble shooting behavior. The fact that the circuits chosen were of a common sort and yet not exactly the same as any gear the men would be expected to have come in contact with reduced differential effects of specialization on certain gears and still permitted the operation of general experiential factors.

The Bases of Problem Selection

Twelve problems (i.e., trouble shooting tasks) were selected from the original 30 developed for MASTS use. The principal criterion for problem selection was the correlation between success on the problem when given in the MASTS format and success in locating and repairing troubles in the actual equipments. Care was also taken to choose problems which were representative of different stages of the equipment, different types of faulty components, and a variety of symptoms. The faults selected were typical of those which normally occur in such equipment.

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1. This kit consists of many individual stage chassis. For example, the radio power supply is a separate stage, the R-F amplifier is another stage, and so on. Each chassis has plugs for coupling to other stages and for making ground and power connections.

Description of the Problems

The problem information presented on the problem-information disks was obtained by taking readings between each of the numbered test points and ground with each type of test equipment under the circumstances of each problem.

Twelve AUTOMASTS problems is the maximum feasible number for a half day of group testing. Although a longer test would have important psychometric advantages, it could not be conducted within realistic time limits.[12]

Four types of electronic circuit components provide the loci for the AUTOMASTS problems. Table 1 shows the tubes, resistors,

Table 1

Types of Components Serving as Loci for Troubles in Problems Selected for AUTOMASTS Administration

Type of Component*	Number of Times Represented in: Radio Circuit	Radar Circuit
Tube	1	1
Resistor	2	3
Capacitor	2	1
Lead	1	1

*Each trouble consists of one faulty component, although a casualty may reflect throughout the circuit.

[12] However, the AUTOMASTS format permits the administration of more problems per unit time than the job sample test upon which it is based. The maximum time limit for twelve problems in AUTOMASTS form (less instructions) is 2-1/2 hours. The same problems in the equipment require a maximum time limit of 7 hours.

capacitors, and leads used in each circuit. No troubles are located in the radio speaker or the cathode ray tube of the radar sweep generator circuit. Transformer troubles are indistinguishable from troubles located in the leads to the transformer. Since defective leads are more easily obtained than defective transformers, the faulty leads are used.

Four types of defects were incorporated in the AUTOMASTS problems. A component could be open, shorted, detuned, or of the wrong value. Table 2 shows the distribution of these defects in the two circuits. All of the defective components selected for use produced a noticeable effect upon the output of the prototype equipments.[13]

Table 2

Nature of Defects Represented in Problems Selected for AUTOMASTS Administration

Nature of Defect	Number of Times Represented in: Radio Circuit	Radar Circuit
Open component	3	3
Shorted component	1	2
Detuned component	1	0
Wrong value component	1	1

[13] Normal output for the receiver was faithful reproduction at the speaker of signals received within the commerical broadcast band. Normal output for the radar sweep circuit consisted of a number of vertical pips equally spaced along the horizontal sweep of the monitor scope.

While it is not possible to represent all of the stages in the circuits with such a small number of problems, efforts were made to select problems which were distributed throughout the equipment (i.e., not all in the same stage). The locations of the defective components employed are given in Tables 3 and 4.

Table 3

Radio Receiver Stages in which Defective Components were Located

Stage	Number of Problems in which Defective Component was in this Stage
Audio voltage amplifier	2
Detector	2
I-F amplifier	1
R-F converter	1

Table 4

Radar Sweep Generator Circuit Stages in which Defective Components were Located

Stage	Number of Problems in which Defective Component was in this Stage
Single swing blocking oscillator	1
Trigger blocking oscillator	1
One shot multivibrator	2
Sawtooth generator	1
Monitor oscilloscope	1

The defective components which produce the "troubles" for the AUTOMASTS problems represent different types of electronic functions within the normally operating equipment. For example, one of the two defective radio capacitors acts as a by-pass capacitor while the other is a tuneable element in a tank circuit.

The symptoms for the malfunctions consist of the output characteristics of the equipments when the faulty part is inserted. These symptoms are depicted for the subject on a small card exposed at the beginning of each problem. Three different symptoms are used for the radio problems. They were: "no sound at any station" (indicating that no sound was produced at the loudspeaker even though the equipment was turned on and the tuning dial was adjusted to the frequency of a commerical broadcast station), "weak signal at all stations," and "very weak signal at all stations." Five different radar symptoms were represented. The symptom card showed a diagram of the face of the monitor scope. The symptoms portrayed the base line without vertical pips, with irregularly spaced pips, without a horizontal sweep, and in one problem the entire pattern on the face of the scope was off centered.

IV. ADMINISTRATION OF THE AUTOMASTS TEST

General

The AUTOMASTS is especially designed for group administration, and the number of subjects that can be tested at one time is limited principally by the number of machines and the amount of space avail-

able. The present administrative procedures have been applied in the field to groups of five subjects at a time; probably no major changes in procedure would be necessary for administering the AUTOMASTS to larger groups.

Situational Requirements

Each subject is provided with an AUTOMASTS machine, a schematic, and a reference manual for the equipment he is trouble shooting. For each man, a desk-height working surface of about 3 x 4 feet is required. It is desirable to provide individual desks or tables so that each man can work independently. Most subjects like to alternate between standing and sitting as they work; the AUTOMASTS can be operated from either position. Ordinary classroom lighting is sufficient for AUTOMASTS testing as the instrument makes no special visual demands on the subject. Each machine must be connected to an electrical outlet to provide current for the cutoff timer and effect indicator light systems.

Time Requirements

The present AUTOMASTS Test consists of twelve problems, six with a ten-minute cutoff and six with a fifteen-minute cutoff. The average group administration time is about three and one-half hours. This time allows for slower subjects who take almost the full time limit on every problem. Of course, if the group is composed of fast trouble shooters the test can be administered in a shorter time.

Testing Procedures

Before the test problems are introduced each subject partici-

pates in a training session to acquaint him with the testing procedures and the circuits with which he is to work. The bulk of the instruction is presented in the form of a tape-recorded lecture. This procedure frees the examiner so that he can clarify and amplify parts of the instructions, if necessary. Pauses during the tape-recorded instructions permit the examiner to demonstrate features of the AUTOMASTS machine. While the record is being played he observes each subject to be sure that the instructions are being carried out properly.

Typical Testing Session

Radio orientation. In the typical testing session the radio receiver problems are given first. During the training period the receiver is described carefully, and each subject notes the different stages and signal paths on his own schematic. The numbering system for test points and components is made explicit, and the subjects are required to show that they understand the staging and numbering system by finding several standardized check points.

Next, the subjects are shown how to set the machine for the different test points and how to adjust the slide-pointer to give the different types of readings. The features of the machine which prevent the subject from taking more than one reading at a time are demonstrated.

At the conclusion of the instructions covering the use of the signal generator a five minute period is devoted to taking practice readings on the set of normal receiver readings in the machine. During this time, the subjects are encouraged to consult their equipment manuals and verify some of the normal voltage readings and parts specifica-

tions that are given there. The five minute period has been found to be adequate for the taking of practice readings on the present equipment; longer periods might be necessary if more complex equipments were adapted to the AUTOMASTS format.

The effect indicator light and delay systems are graphically presented to the subjects by having them "replace" a faulty component while the normal information disk is in the machine. The normal disk has been equipped so that replacing one of the parts will give a "gear normal" indication; each subject is told to replace this part and observe the green light, then to replace any other part and observe the red or "no effect" light.

The instructions are very thorough. It takes almost half an hour to bring technicians to the point where they are ready for a practice trouble shooting problem. Field experience indicates that the time spent on thorough instruction is well justified.

Radio practice problem. After the radio orientation procedures, each subject is given a radio familiarization problem. He is presented with a symptom card and told to trouble shoot the equipment by taking readings and replacing parts. During the practice problem, the examiner answers any questions that the subject may have about the operation of the machine or the general characteristics of the electronics equipment.

The practice problem is rather easy and most sujects solve it before the ten minute time limit. Unsuccessful subjects are given the answer to the practice problem before proceeding, and they have an opportunity to take a few readings to "verify" the answer.

Radio test problems. For each test problem, a new problem-information disk is inserted in the machine, the paper tape is advanced several inches, and the technician is given a new symptom card which describes the gross output symptoms of the actual equipment. The subject works alone during the trouble shooting task. No questions or interruptions are permitted during the test problems. If the technician questions the validity of particular information that he gets from the machine, he is told that the problem information has been checked and standardized, and that he will have a later opportunity to discuss special points.

A total of six radio problems are administered with a time limit of ten minutes per problem. All subjects take the same problems in the same order. If a subject fails to solve a problem within the time limit, the machine locks and he is informed of the correct answer before going on to the next problem.

Radar orientation. When all subjects have finished the radio problems, the radar problem-information disk showing the readings obtained when the radar equipment was functioning normally is placed in the machine. A tape-recorded radar orientation lecture is played to the group. The radar instructions are similar to the radio instructions in that each subject is led through the schematic and is required to take standardized readings from the machine. However, the radar orientation is accomplished in only 15 minutes because the subjects are already familiar with the operating features of the testing machine.

Radar practice problem. At the conclusion of the radar orientation lecture each subject works a simple radar practice problem.

This procedure permits the men to demonstrate that they have understood the instructions and have achieved a degree of familiarity with the circuit. Almost all men solve the practice problem within the 15 minute time limit. The examiner works with any subject having difficulty during the practice problem.

Radar test problems. The radar problems are administered in the same manner as the radio problems. A new problem-information disk and symptom card is used for each problem. If a technician does not solve a problem within the 15 minute cutoff time, he is given the correct answer before going on.[14]

Performance records. The examiner enters the time required by the subject to solve each problem on a standard form. At the end of the complete AUTOMASTS session, the printed tape is removed from the machine. The tape of trouble shooting responses and the AUTOMASTS time records constitute the basic data of the test.

V. PLANS FOR ANALYSIS OF DATA

The AUTOMASTS data constitute a real challenge to the data analyst because there are so many possibilities for scoring[15] the

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[14] There were two reasons for doing this: (1) to provide closure, and (2) to provide a better understanding of the dynamic features of the circuit. This latter was to reduce the advantages which might accrue to those who solved the initial problem over those who did not.

[15] In this report, the term "scoring" refers to the process of abstracting certain quantifiable features from the behavioral records.

trouble shooting performance. The general plan adopted here is to develop as large a variety of scoring methods as possible and to apply them to data collected in the field. An empirical study of the relationships between the various score parameters can then be expected to lead to (1) a better understanding of the trouble shooting process, (2) bases for combining different scores, and (3) improved predictive properties of the AUTOMASTS test.

The discussion below mentions the types of scoring procedures which are now being applied to AUTOMASTS data. Many of these have been proposed or applied by other investigators, and the present collection of scoring methods will undoubtedly be supplemented and modified as the analysis proceeds.

Certain end products are conventionally derived from performance test records. A testee is usually given credit for the <u>number of tasks he successfully performs</u> or the number of troubles he finds under the circumstances of the test. The principal difficulties in relying solely upon this score are: (1) practical factors necessitate a relatively small number of items and a consequently restricted range of scores and (2) the end-product score ignores all the process information contained in the response records. If each trouble shooting problem is regarded as an item in a test,[16] the discriminating power of each item may be

[16] Technical Report No. 9 discusses the rationale for considering each problem as a test item, or each problem as a test. The latter offers many important advantages but adequate means for scoring the records are not currently available. It is expected that the present investigation of scoring will be of value in the treatment of each problem as a test.

improved by taking the response records into account and giving partial credit for incomplete solutions which are "on the right track." In an electronic circuit such partial credit can be earned by isolating[17] the trouble to the correct stage.[18] Technicians can be given still additional credit if they remain in the correct area after they have isolated the trouble to the area.

Response records also provide scores on negative aspects of the performance. For example, Glaser[19] has suggested that redundant checks, or checks that produce no new information, be negatively weighted. Isolation to an incorrect stage or functional unit and replacement of components that are not faulty also seem to indicate wrong or inefficient interpretations by the technician subject. There are error checks which could not conceivably give information about any trouble (voltage measurements at ground) or which represent faulty or inappropriate use of test equipment (injection of signals into power supply).

Not all potential scoring parameters may be definitely assigned

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[17]One possible criterion for isolation consists of a minimum consecutive number of steps in the stage in question.

[18]This same form of analysis may be carried out using units smaller than a stage. Present plans include an analysis of the response records in terms of "functional units." Functional units are designated on the bases of a somewhat arbitrary breakdown of each stage into closely related elements. For example, the plate circuit of the IF amplifier is a functional unit. The radio receiver has eight stages and forty-six functional units, while the radar circuit consists of ten stages and forty-two functional units.

[19]Glaser, Robert B. A Proficiency Test Battery for Guided Missile Technicians. Pittsburgh: American Institute for Research, 1953.

positive or negative weights. Instead, many measures most properly should be considered as scoring hypotheses. In some cases, predictions of the positive or negative nature of the scores can be made on the basis of previous research,[20] while other scores are frankly exploratory. As indicated above, the records are being scored along these parameters in order to empirically determine the relationships among these and more conventional measures. One such parameter is time-to-solution. It may be argued that the best technicians (by definition) are the ones who accomplish their repairs most speedily. On the other hand, many experienced technicians urge caution and deliberation in the approach to the problem. Comparison of time-to-solution scores will reveal whether or not the speedy repairmen are generally more successful than slow technicians under the circumstances of the AUTOMASTS test.

The number of steps or actions accomplished by the technician during a problem is amenable to the same kind of analysis. It has been proposed that a relatively small number of steps is indicative of economy or efficiency.[21] However, a small number of steps may not be predictive of other measures of performance. These relationships must be empirically investigated before it is assumed that economy is coordinate with success.

Various measures of the error distance or degree of removal of

[20] Saupe, Joseph L. Trouble Shooting Electronic Equipment. Urbana: Bureau of Educational Research, University of Illinois, 1954, 127 p.

[21] Glaser, op. cit.

the responses from the actual site of the trouble may be useful. In a mechanical trouble shooting situation, Fattu, Mech, and Kapos[22] used the number of functional units separating the response from the trouble as a basis for error distance scores. This same system can be applied to electronic equipment. A similar error distance score may be derived in a different manner. The readings for a given problem can be classified as critical information readings (lead directly to trouble), non-critical information readings (provide useful information but do not furnish positive localization), and no information readings. Each response can then be weighted according to membership in one of the three classes of readings and all steps averaged into a weighted distance index.

The critical information readings are direct clues to the faulty component. A score of the critical clue utilization can be determined by counting the number of times that critical clues were obtained but not utilized, (i.e., without the indicated subsequent responses being made).

Since all the checks made are identifiable from the response record, it is possible to score the technician in terms of hypotheses tested (parts replaced) as a result of guesses. If a component is replaced or adjusted without previous checks being made which would supply clues relative to that part, then the replacement is counted as a guess.

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[22] Fattu, N. A., Mech, E., and Kapos, E. Some statistical relationships between selected response dimensions and problem-solving proficiency. Psychol. Monogr., 1954, 68, No. 6 (Whole No. 377).

A tabulation of the frequency of types of checks or readings can reveal individual differences in test equipment usage.

It may be useful to fractionate the response records on the basis of the number of responses. For example, splitting the performance of each man into quarters will allow frequency comparisons of entries in different functional units for each quarter of the performance.

Most of the scoring methods mentioned above have not involved the sequential order of all of the steps taken in the trouble shooting task. The extremely large number of possible orders imposes great practical difficulties on such analyses, and yet the order of the responses is clearly one of the most important features of the performance. Evaluation of the technician's method or solution scheme depends on the sequence of the steps.

Present attempts to deal with the sequence of responses have been along two lines. The first approach involves the behavioral definition of some particular trouble shooting system.[23] The system requires definite classes of responses to be made in a certain order. Response records are then examined to determine the degree of adherence to the system. The result is a score which expresses how nearly the technician conforms to the system used as a standard. If this kind of analysis proves feasible, it can answer such questions as "Do all technicians use the same trouble shooting method for a given problem or type of symptom," "How many trouble shooting methods are discernible from AUTOMASTS data," or "Do successful technicians employ a method which

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[23] "Ideal" systems have been proposed on logical grounds, and ordered checking sequences are often suggested by equipment manufacturers.

is different from that of unsuccessful technicians"? If the latter question can be answered in the affirmative, then technicians could be graded on their degree of adherence to the successful method.

A second approach to evaluating sequence consists of classifying the total response pattern into several categories of types of attack. Sets of categories have been applied by Cornell, Damrin, and Saupe,[24] and by Saupe.[25] This method requires the judgments of several experts in order to estimate the reliability of the classification.

About thirty different scores are now being applied to AUTOMASTS response records. Detailed descriptions of the various scores and the relationships between them will be presented in later reports of this series.

VI. DISCUSSION

The results of the administration of the AUTOMASTS will be presented in detail in Technical Report No. 12. The ultimate worth of the AUTOMASTS must be judged in terms of its results and their contribution to better understanding of the trouble shooting process and its measurement. However, at this point it is appropriate to

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[24] Cornell, Francis G., Damrin, Dora E., and Saupe, Joe L. The AN/APQ-24 Radar Mechanics' Proficiency Testing Study, the Tab Test: A Group Test Simulating Performance Behavior for the Measurement of Proficiency in Diagnostic Problem-solving Tasks. Urbana: Bureau of Educational Research, University of Illinois, 1954. 44 p.

[25] Saupe, op. cit.

reexamine the objectives set for the test format (i.e., the testing machines and procedures) and to appraise the extent to which these objectives have been achieved. The specific test content (i.e., the particular circuits, troubles, scoring systems, and psychometric properties of the present test) will be evaluated in the later reports.

At the outset it is important to point out that the present machines must be regarded as prototype models. Competent engineers will be able to devise far better pieces of hardware. Even the present investigators see many opportunities for improvement of the existing models. Despite this fact, the machines appear to have done the job for which they were designed. They produce permanent, sequential records of the steps technicians take in diagnosing and correcting difficulties in electronic equipment. They present the technician with an "open-ended" and realistic problem, i.e., they make a large number of items of information available to him but require the technician to supply his own procedures for sampling and interpreting the information. They do not restrict the behavior of the men in such a way that one particular method of trouble shooting is favored over another. The men are free to trouble shoot in the manner to which they are accustomed.

The machines are portable and rugged. They make possible group administration of this type of trouble shooting problem. They also expedite the trouble shooting procedures so that the same problems which required a 35-minute cutoff time in the job sample format may be successfully administered with a 15 or 10 minute cutoff time in the AUTOMASTS form. The test may be administered by persons without special

training in electronics.

The machines may be used for a wide variety of problems involving different circuits. In order to employ new circuits or new problems, only the reference materials and the paper portion of the problem-information disk need be changed. For this reason the machines will be adapted for further research as indicated below.

Men who have taken AUTOMASTS problems report that they "feel" they are trouble shooting. Several have suggested applications for the test. Many pointed out possibilities for the test as a training device. Most of the men indicated that this form of test covered a part of their jobs that was not covered by an extensive battery of job-oriented paper-and-pencil tests.

Despite the fact that the AUTOMASTS seems to have lived up to expectations one should not lose sight of the fact that it is still relatively untested and that an important part of the research yet to be done with respect to the AUTOMASTS is to determine its limitations. In addition to this general methodological research, future plans for the use of the AUTOMASTS technique include the following:

1. Development of more adequate testing machines. In general this development will be carried out by groups especially oriented toward hardware development although modifications of the five pilot models will be made as necessary to conduct elements of the research mentioned below. It is felt that a completely self-administering form of the test (e.g., with automatic problem-changer) can be and should be developed. If this transpires, and

if a sufficient number of these machines are produced, vast quantities of data will become available for study. This will be a very important contribution to the analysis of trouble shooting behavior. The paucity of such information is one of the reasons that many of the problems involved in the analysis and measurement of electronics trouble shooting cannot be attacked at this time. When a large number of response records are available numerous hypotheses regarding the nature of trouble shooting behavior may be subjected to test.

2. Development of a set of problems based on Navy equipment. A second projected use of the AUTOMASTS testing system is to develop a set of problems based on operational Navy equipment for use in the machines. Additional plans are being made for the development of problems involving so-called "fundamental" circuits. When problems have been developed on a number of different kinds of circuits and equipments it will be possible to investigate such important areas as the transfer which occurs between trouble shooting one type of electronic equipment and another.

3. Evaluation of the AUTOMASTS as a training device. Plans are currently being formulated for the conduct of training research with the present AUTOMASTS. The objectives of this research would be two-fold: first, to determine the usefulness of the AUTOMASTS Test as a training device, and second, if the device proves to be useful as a trainer, to develop a training program which can be used aboard ship and in training schools to supplement for trouble shooting the actual equipments.

4. <u>Determination of the relationship between duty assignment and trouble shooting skill.</u> Present plans also include the possibility of employing the AUTOMASTS to determine the extent to which men have lost the ability to trouble shoot as a result of periods spent away from trouble shooting assignments. A similar problem to be investigated is the effects of protracted specialized assignments (such as a tour of duty at a land-based transmitter station) upon trouble shooting performance.

5. <u>Comparison of trouble shooting methods.</u> The response records produced by the AUTOMASTS provide a suitable basis for comparative evaluation of various trouble shooting methods or systems. Matched groups of experimental subjects may be trained to trouble shoot according to specified procedures. At the conclusion of the training period the entire group can be tested on the AUTOMASTS in order to evaluate the efficacy of the different procedures. Under appropriate conditions of experimental control, this procedure will also uncover interactions between trouble shooting methods and problem types (if such interactions exist).

6. <u>Analysis of trouble shooting problems.</u> Since the AUTOMASTS permits experimental control of the problem information furnished the technician it is possible to systematically investigate such factors as what makes a problem hard or easy; or what role extensiveness of cues, circuit complexity, and type of circuit play in the trouble shooting process.

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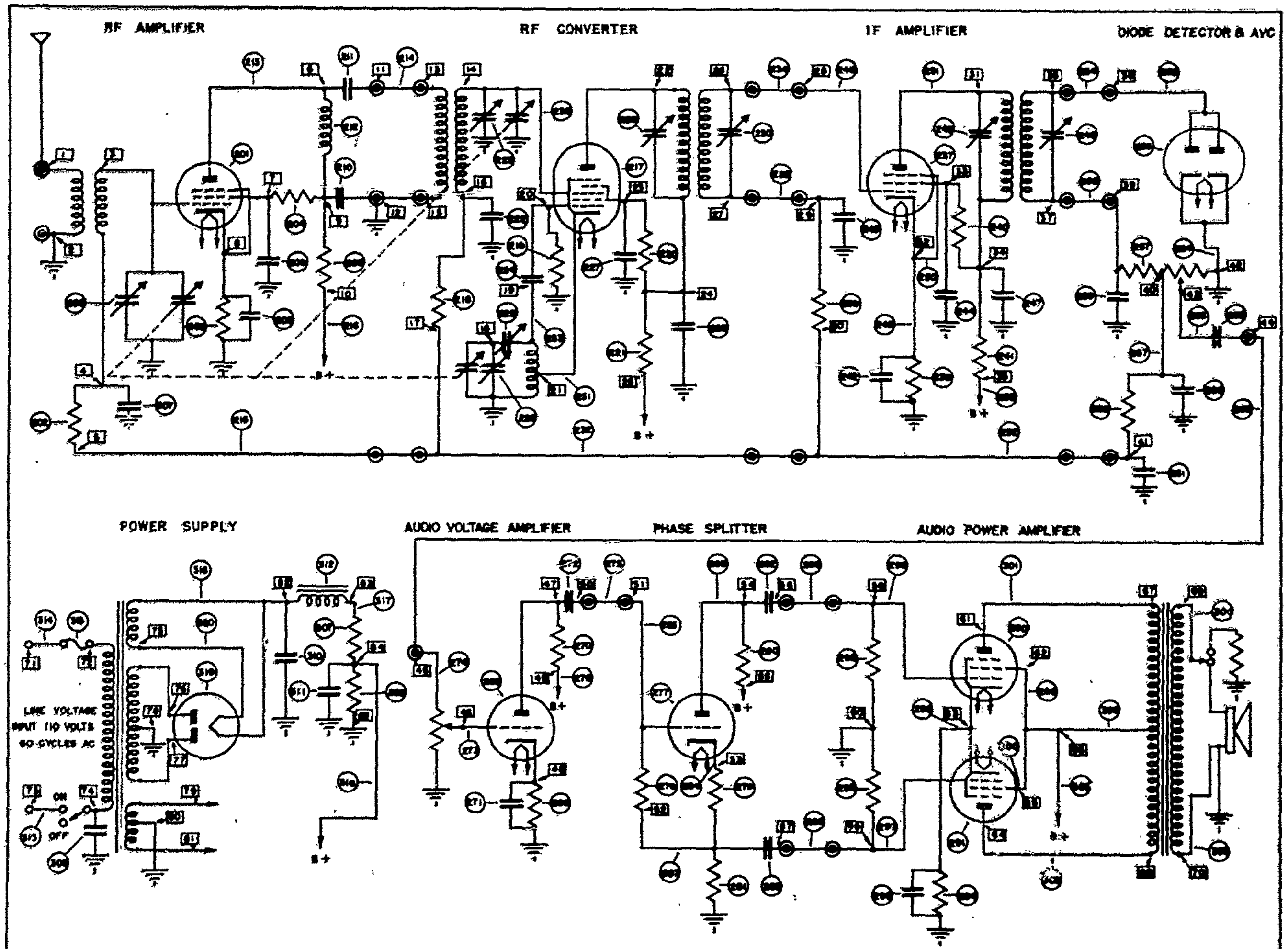
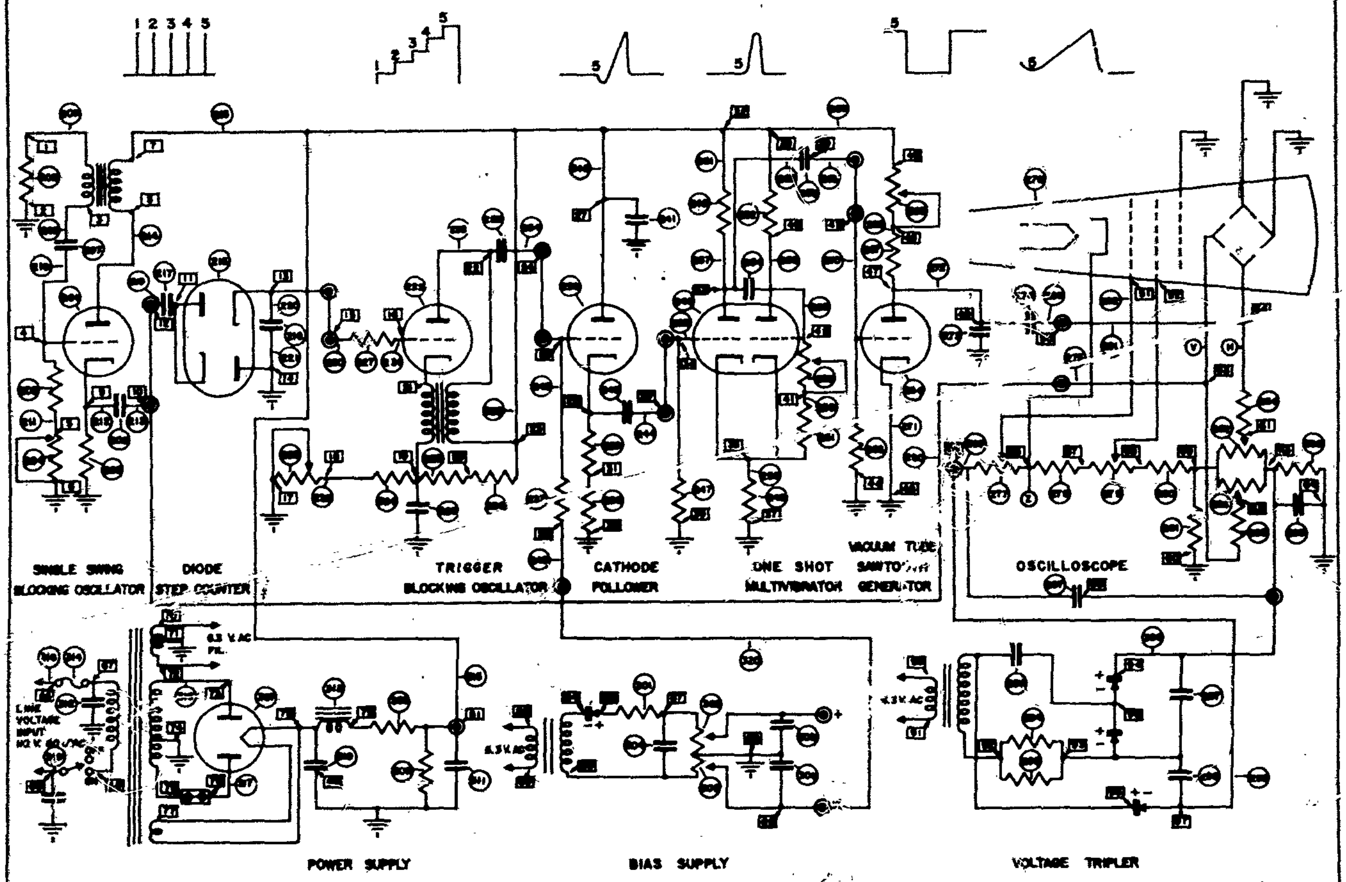
APPENDIX

This appendix contains schematic diagrams of the equipments currently being used for AUTOMASTS trouble shooting problems. The diagrams shown here have been drastically reduced in size from the schematics actually used in AUTOMASTS testing. On both schematics, test point numbers are in boxes and component numbers are circled.

These schematics are specially adapted versions of the original schematics published by the Philco Corporation in NAVSHIPS 900170 Electronics training Series.



BASIC RADIO RECEIVER CIRCUIT DIAGRAM



BASIC RADAR SWEEP GENERATOR CIRCUIT DIAGRAM